Poster: Adaptive Topology Control for Wireless Ad-hoc Networks[*]

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ABSTRACT

Topology control in ad-hoc networks is the problem of adjusting the transmission power at network nodes in order to achieve the optimal topology that maximizes network performance. Recently, using effective topology control to optimize energy usage in the network has come into focus in the research community[1, 2]. The common thesis arrived at by existing works is that the transmission range used by mobile nodes should be the minimum required to keep the network connected. We refer to such a topology as the *minimally connected topology* in the rest of the paper. We argue in this work that the minimally connected topology does not always provide the optimal performance in typical ad-hoc networks. We show that in contrast, for typical ad-hoc networks with a few hundred nodes distributed over a few square miles area, the optimal topology is a function of the traffic load.

1. BASIS FOR THE MYTH

The reasons for the presumed optimality of the minimally connected topology can be explained as follows. When the transmission range is decreased, the average hop-count for the paths traversed by flows increases linearly. However, the transmission power per hop decreases super linearly (given that the path loss exponent typically ranges from 2 to 4). Hence, the overall energy consumption in the network for the same amount of data transferred is minimized in a minimally connected topology. Furthermore, when the transmission range in a network is decreased, the average hop-count of flows in the network increases, which in turn increases the total number of one-hop flows (mini-flows) in the network increases, thus increasing the aggregate *induced load* in the network (We distinguish the basic load offered by the sources of the flows from the induced load that is the basic load multiplied by the average number of hops traversed by flows.). However, a decrease in the transmission range also increases the *spatial re-use* in the network, thus increasing the network capacity. It can be shown that, with a decrease in transmission range, while hop-count increases linearly, the spatial re-use in fact increases quadratically since the inhibition area of a transmission is proportional to the square of the transmission range. Hence, any increase in the aggregate induced load in the network is easily offset by the higher spatial re-use in the network, thus leaving the throughput unaffected for the same basic load in the network.

2. EXPOSING THE MYTH

While a minimally connected topology is indeed optimal for generic ad-hoc networks, in this paper we show that for *typical ad-hoc networks* consisting of a few hundred nodes distributed in a few square-miles region, this is not true. Essentially, in such environments, the spatial re-use in the network does not scale as well as the hop-count when the transmission range is decreased. Thus, when the transmission range is minimized, the induced load in the network increases without a correspondingly equal increase in the capacity of the network. Due to this anomaly, the basic load in the network gains significance in terms of determining the efficacy of a particular network topology. For instance, if the basic load is low enough such that the induced load in a minimally connected topology is below the network capacity, optimal performance will still be achieved when the transmission range is minimized to achieve such a topology. However, if the basic load is high enough to cause the induced load to exceed the network capacity, due to the network operating under overloaded conditions, the observed throughput can fall drastically.

2.1 Experiments and Observations

We use ns2 based simulations to study the throughput per unit energy performance of an 100 nodes, 1000m$\times$1000m grid ad-hoc network under different load conditions and different transmission ranges using a CBR/UDP/DSR/CSMA/CA protocol stack. In Figure 1 (a), we observe the non optimality of the minimally connected topology for higher loads. It can be observed that (i) for the lightly loaded scenario, the maximum per-flow throughput is achieved at a transmission range of 300m; (ii) for the moderately loaded scenario, the maximum per-flow throughput is achieved at a transmission range of approximately 600m, and (iii) for the heavily loaded scenario, the utilization is poor and the maximum throughput is achieved approximately at 500m. This illustrates that for a given topology, the optimal transmission range (in terms of throughput) is variable, and is a function of the load.

2.2 Insights

Essentially, under low load conditions, it is desirable to operate using the minimally connected topology as the throughput perfor-

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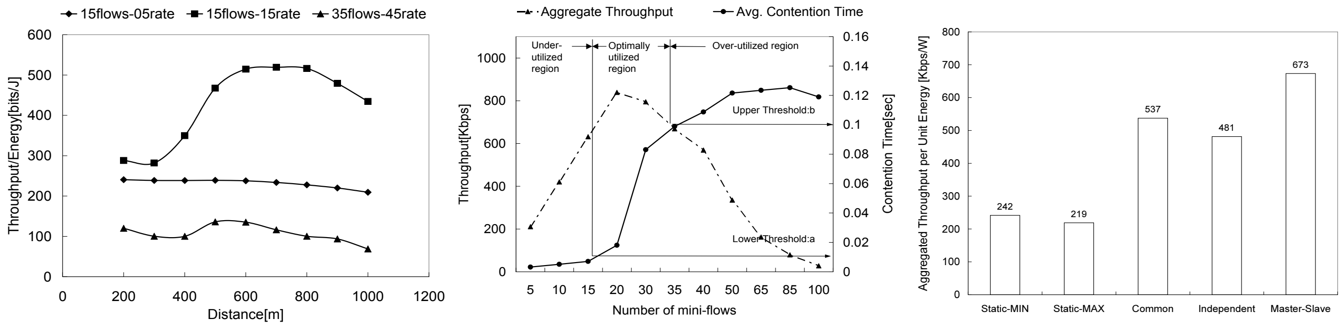

(a) (b) (c)

Figure 1: (a): Throughput per unit energy as a function of transmission distance for different traffic loads: low load, moderate load, and heavy load, (b): Relationship between traffic load and contention time as a function of the number of mini-flows within a mini-channel, for the case of 15 packets per second per flow, and (c): Throughput per unit energy performance of different topology control schemes: 100 mobile nodes located in 1000m×1000m area and variable load.

mance does not degrade, and at the same time the energy consumption is minimized. *However, for moderate loads, it is desirable to reduce the transmission range only to the point where the induced load causes the utilization of a mini-channel (two-hop region) to reach its peak.* At this transmission range, the throughput is still maintained while the energy consumption is reduced to the minimum possible while not pushing the mini-channel to the over-utilization region. For heavy load conditions, since the basic load by itself pushes the mini-channel utilization to the over-utilized region (thus causing the throughput to be very low), it is desirable to operate at the minimum transmission range required to keep the network connected.

3. ADDRESSING THE MYTH: ADAPTIVE TOPOLOGY CONTROL

We adopt a local heuristic based method to adapt the transmission power at mobile stations. It involves a three step procedure, each of which is described below:

Estimation of Traffic Load within a Mini-channel

To estimate the traffic load of each mini-channel, each node measures the local contention time. Figure 1 (b) shows the relationship between traffic load and contention time in a mini-channel for different packet transmission rates. Similar relationships hold for other rates of packet transmissions. To identify the traffic load of a region, a node uses two thresholds for the contention time: (i) α, a lower bound for an optimally utilized region and (ii) β, an upper bound for the optimally utilized region. Through observations from simulation results for different packet transmission rates(see figure 1(b)), we empirically choose 0.01 and 0.1 seconds, as the lower threshold α and upper threshold β, respectively.

Adapting Transmission Power

After measuring the contention time, each node can identify the current status of utilization within its mini-channel. Upon inferring over-utilization, a node increases the transmission power to enlarge the area of its mini-channel, which in turn will reduce the number of mini-flows. On the other hand, in case of under-utilization, a node will decrease the transmission power, which will increase the number of mini-flows. Note that the increase decision is motivated by the desire for increasing throughput by going from the over-utilized region to the optimally utilized region. On the other hand, the decrease decision is motivated by the desire for decreasing energy consumption by going from the under-utilized region to the optimally utilized region.

Coordination

In this paper, we propose three different adaptive topology control algorithms that employ the previous two stages, but differ based on how they coordinate with other nodes in the network after deciding on the transmission power to use: (i) ATC-CP, adaptive topology control scheme in which all nodes use a common power, (ii) ATC-IP, adaptive topology control scheme in which each node independently uses its locally determined transmission power, and (iii) ATC-MS, adaptive topology control scheme that employs a one-hop master-slave coordination. Briefly, ATC-CP is targeted for networks where the underlying routing and MAC protocols assume that all nodes in the network use the same transmission range. On the other hand, ATC-IP allows nodes in the network to independently adjust the transmission power. Finally, in ATC-MS, nodes independently adjust transmission power, except for coordination between one-hop neighbors.

4. PERFORMANCE EVALUATION

We evaluate the throughput per unit energy performance of the proposed algorithms, along with those of the static (minimum and maximum transmission power) approaches. We observe the improvement in performance for a scenario with 100 mobile nodes with maximum speeds ranges up to 20 meters per second. The network area is 1000m×1000m. The load in the network is dynamically varied between 10 flows to 25 UDP flows throughout the period of the simulation with each flow sending at a rate of 20Kbps. The channel data rate is 2Mbps. Figures 1 (c) shows that, in the presence of mobility, ATC-MS achieves the best performance over the other schemes. As expected, the static control scheme with minimum power performs the worst.

5. REFERENCES

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